

# TECHNICAL MEMORANDUM

## X-199

STABILITY INVESTIGATION OF A BLUNTED CONE AND A BLUNTED  
OGIVE WITH A FLARED CYLINDER AFTERBODY AT  
MACH NUMBERS FROM 0.30 TO 2.85

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STABILITY INVESTIGATION OF A BLUNTED CONE AND A BLUNTED  
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SUMMARY

A cone with a blunt nose tip and a  $10.7^\circ$  cone half angle and an ogive with a blunt nose tip and a  $20^\circ$  flared cylinder afterbody have been tested in free flight over a Mach number range of 0.30 to 2.85 and a Reynolds number range of  $1 \times 10^6$  to  $23 \times 10^6$ . Time histories, cross plots of force and moment coefficients, and plots of the longitudinal force coefficient, rolling velocity, aerodynamic center, normal-force-curve slope, and dynamic stability are presented. With the center-of-gravity location at about 50 percent of the model length, the models were both statically and dynamically stable throughout the Mach number range. For the cone, the average aerodynamic center moved slightly forward with decreasing speeds and the normal-force-curve slope was fairly constant throughout the speed range. For the ogive, the average aerodynamic center remained practically constant and the normal-force-curve slope remained practically constant to a Mach number of approximately 1.6 where a rising trend is noted. Maximum drag coefficient for the cone, with reference to the base area, was approximately 0.6, and for the ogive, with reference to the area of the cylindrical portion, was approximately 2.1.

INTRODUCTION

Static and dynamic stability characteristics of low-fineness-ratio blunt shapes are required in the design of current reentry bodies. This paper presents aerodynamic data from flight tests of two such shapes, a blunted cone with a  $10.7^\circ$  cone half angle and a blunted ogive with a  $20^\circ$  flared afterbody. These tests covered a Mach number range from 0.30

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to 2.85 and a Reynolds number range from  $1 \times 10^6$  to  $23 \times 10^6$ , with reference to the base diameter for the cone and to the diameter of the cylindrical portion for the ogive. The free-flight tests were conducted at the NASA Wallops Station at Wallops Island, Virginia.

### SYMBOLS

The data are presented relative to the body-axis system and the positive directions of the force coefficients, moment coefficients, and angular velocities are shown in figure 1. The various symbols used throughout the paper are defined as follows:

$a$  accelerometer reading, g units

$C_C$  longitudinal-force coefficient,  $a_{l, cg} \frac{W/S}{q}$

$C_l$  rolling-moment coefficient

$C_m$  pitching-moment coefficient,  $\frac{I_Y}{qSd}(\ddot{\theta} - \dot{\psi}\dot{\phi})$

$$C_{mq} + C_{m\dot{\alpha}} = \frac{dC_m}{d\dot{\theta}d} + \frac{dC_m}{d\dot{\alpha}d}$$

$C_N$  normal-force coefficient,  $a_{n, cg} \frac{W/S}{q}$

$$C_{N\alpha} = \frac{dC_N}{d\alpha}$$

$C_n$  yawing-moment coefficient,  $\frac{I_Z}{qSd}(\ddot{\psi} + \dot{\theta}\dot{\phi})$

$C_Y$  lateral-force coefficient,  $a_{t, cg} \frac{W/S}{q}$

$d$  reference diameter (see fig. 2), ft

$g$  acceleration due to gravity, ft/sec<sup>2</sup>

$I$  moment of inertia about Y- or Z-axis, slug-ft<sup>2</sup>

$I_X$	moment of inertia about X-axis, slug-ft <sup>2</sup>
$l$	length of model, ft
$M$	Mach number
$q$	dynamic pressure, lb/sq ft
$R$	Reynolds number per foot
$S$	reference area of model used in coefficients, sq ft
$t$	time, sec
$V$	free-stream velocity, ft/sec
$W$	weight of model, lb
$X, Y, Z$	coordinate axes
$x$	distance from center of gravity, positive forward, ft
$x_{ac}$	aerodynamic-center position measured from the nose, ft
$x_{cg}$	center-of-gravity position measured from the nose, ft
$\alpha$	angle of attack, radians
$\theta$	angle of pitch
$\lambda_0$	nonrolling damping constant, 1/sec
$\Delta\lambda$	damping constant due to roll, 1/sec
$\varphi$	angle of roll, radians
$\psi$	angle of yaw, radians
$\omega_0$	basic oscillation frequency, radians/sec
$\Delta\omega$	component of total pitch frequency resulting directly from roll, radians/sec
$\ddot{\theta} - \dot{\psi}\dot{\varphi}$	effective pitching acceleration, $g \frac{a_{n,2} - a_{n,1}}{x_{n,2} - x_{n,1}}$ , radians/sec <sup>2</sup>

$a_{n,cg}$  normal acceleration,  $\frac{a_{n,1}x_{n,2} - a_{n,2}x_{n,1}}{x_{n,2} - x_{n,1}}$ , g units

$\ddot{\psi} + \dot{\theta}\dot{\phi}$  effective yawing acceleration,  $g \frac{a_{t,2} - a_{t,1}}{x_{t,2} - x_{t,1}}$ , radians/sec<sup>2</sup>

$a_{t,cg}$  transverse acceleration,  $\frac{a_{t,1}x_{t,2} - a_{t,2}x_{t,1}}{x_{t,2} - x_{t,1}}$ , g units

Subscripts:

l longitudinal  
 n normal  
 t transverse  
 1 forward end of model  
 2 rear end of model

A dot above a symbol indicates time rate of change of symbol, for example,  $\dot{\theta} = \frac{\partial \theta}{\partial t}$ .

#### MODELS

The physical characteristics of the models are presented in table I, and drawings of the models are shown in figure 2. Photographs of the models and model booster arrangements are presented in figure 3.

The cone model of fineness ratio 2.1 had a blunt tip nose and a 10.7° flared body. The ogive model of fineness ratio 3.6 had a blunt nose tip, a circular cylinder forebody, and a 20° flared afterbody. The center of gravity for each model was located at approximately 50 percent of the model length. Each model contained three small pulse rockets to give a lateral disturbance. These pulse rockets were mounted near the base, equally spaced around the model perimeter and normal to the longitudinal axis.

## INSTRUMENTATION

Model instrumentation consisted of an NASA six-channel telemeter which transmitted data from five accelerometers and one roll-rate gyro located as follows: the roll-rate gyro, the longitudinal accelerometer, one normal and one transverse accelerometer in the forward end of the model and one normal and one transverse accelerometer in the rear of the model. Ground instrumentation included a CW Doppler radar unit to measure the velocity of the model, a modified SCR 584 tracking radar set to determine the flight path, and a rollsonde receiver used as an additional measure of the rolling velocity. Fixed and tracking motion-picture cameras were used to observe the model during the first portion of the flight. Atmospheric data were obtained from a rawinsonde released near firing time.

## TESTS AND ANALYSIS

The models were ground launched at an angle of  $70^\circ$  from the horizontal by means of a zero length launcher. A solid-fuel JATO, 1.52-KS-33,550,XM19 (Recruit) rocket motor boosted the models to maximum velocity.

A photograph of the model-booster arrangement is shown in figure 3. The conical flare on the booster was used to provide stability and enough inherent fixed drag to separate the booster from the model. The model was held to the booster by a bolt which breaks in tension through a piston arrangement driven by gas from a powder charge during the booster portion of the flight. When the ogive model was disturbed at separation and by the firing of a pulse rocket, the instruments exceeded their calibrated ranges for a short while. Thus, for this model the peak Mach number range for data purposes was reduced.

Data obtained from normal and transverse accelerometers located at two positions in the model were used to determine the pitching-moment and yawing-moment coefficients. The methods of analysis presented in references 1 and 2 were used for reducing these data. Before determining the damping coefficients, the amplitudes of the oscillations were corrected for the effect of the decreasing dynamic pressure. (See ref. 3.) Applying this correction caused an increase in the values of  $C_{m_q} + C_{m_{\dot{\alpha}}}$  of about 14 percent for the cone model and about 22 percent for the ogive model compared with the values that would have been obtained if no correction had been applied. The values used to determine  $C_{N_{\alpha}}$  and  $C_{m_q} + C_{m_{\dot{\alpha}}}$  are presented in table II.

## ACCURACY

The maximum instrument inaccuracies, estimated to be  $\pm 2$  percent of their calibrated range, are stated in coefficient form for representative Mach numbers as follows:

Coefficient	Cone model at Mach number of -			Ogive model at Mach number of -		
	2.85	1.03	0.32	1.86	1.53	0.64
$C_N$	$\pm 0.001$	$\pm 0.013$	$\pm 0.179$	$\pm 0.011$	$\pm 0.017$	$\pm 0.113$
$C_Y$	$\pm 0.001$	$\pm 0.013$	$\pm 0.182$	$\pm 0.011$	$\pm 0.016$	$\pm 0.111$
$C_C$	$\pm 0.006$	$\pm 0.059$	$\pm 0.842$	$\pm 0.049$	$\pm 0.075$	$\pm 0.504$

## PRESENTATION OF RESULTS

The variation of test Reynolds number, based on reference diameter (see fig. 2), with test Mach number is presented in figure 4. The model flight paths are presented as the variation of altitude with horizontal distance in figure 5, and the variation of velocity and dynamic pressure with time is shown in figure 6.

Time histories of the normal-force coefficient, lateral-force coefficient computed at the center of gravity, and Mach number are presented in figures 7 and 8. Basic-data cross plots of force and moment coefficients are shown in figures 9 and 10. The rolling velocity is shown in figure 11 as a function of Mach number. The variation with Mach number of the average aerodynamic center, the normal-force-curve slope, the dynamic stability, and the measured longitudinal force coefficient are presented in figures 12 and 13.

## DISCUSSION OF RESULTS

## Time History

The time histories of  $C_Y$  and  $C_N$  show the motion of the models caused by the separation from the booster rocket motor and by the firing



of the three pulse rockets. When disturbed, a coupled motion with respect to the body axis system and damping of the oscillations were experienced by both models throughout the flight.

#### Basic Data Plots

Cross plots of  $C_N$  and  $C_Y$  presented in figures 9 and 10 for various Mach numbers indicate the model motion. The trim center was estimated and a time history of the resultant force vector was obtained which was used for determining the values tabulated in table II. The angular displacement of adjacent peaks on the cross plots gives an indication of the rolling rate of the models, and the values obtained are shown in figure 11 with measured averages from the rollsonde and roll-rate gyro.

Pitching- and yawing-moment coefficients as a function of force coefficients are shown in figures 9 and 10 for various Mach numbers. These variations show a stable slope which is very linear throughout the speed range.

#### Aerodynamic Characteristics

The normal-force, chord-force, and stability characteristics plotted against Mach number are shown for the cone and ogive models in figures 12 and 13, respectively. Also included in figure 12 are data of a  $10^\circ$  half-angle cone of reference 4 and data of a  $7.5^\circ$  half-angle cone of references 5 and 6 and some unpublished data for a  $7.5^\circ$  half-angle cone. The models were both statically and dynamically stable throughout the Mach number range about a point located approximately 50 percent of the body length.

For the cone, the average aerodynamic center moved slightly forward with decreasing speeds, and the normal-force-curve slope was fairly constant throughout the speed range. The reference theoretical and experimental cone data showed good agreement with the data of this test. It is seen that the maximum longitudinal-force coefficient value is approximately 0.60 with reference to maximum diameter.

The average aerodynamic center for the ogive model remained practically constant throughout the speed range. The test points for the normal-force-curve slope show little change throughout the speed range for this model except for the point at  $M = 1.86$ . The trend of this value approaches the estimated theoretical values. However, because of the rapid change in the basic oscillation frequency  $\omega_0$ , as can be seen from the time-history plot, it should be treated as a qualitative value.

Theoretical estimates were also made for the aerodynamic-center location. These estimates are based on second-order shock-expansion theory for the ogive-cylinder (ref. 7) and conical flow over the surface of the flare. Maximum drag coefficient, based on the diameter of the cylindrical portion of the model, was approximately 2.1.

#### SUMMARY OF RESULTS

From flight tests, over a Mach number range of 0.30 to 2.85 and a Reynolds number range of  $1 \times 10^6$  to  $23 \times 10^6$ , of a fineness-ratio-2.1 blunted cone of a  $10.7^\circ$  cone half angle and a fineness-ratio-3.6 blunted ogive with a  $20^\circ$  flared afterbody, the following results were obtained.

1. The models were both statically and dynamically stable throughout the Mach number range with the center of gravity located at approximately 50 percent of the body length. For the cone, the average aerodynamic center moved slightly forward with decreasing speeds and the normal-force-curve slope remained fairly constant throughout the speed range. Good agreement with theory was obtained. For the ogive, the average aerodynamic center remained practically constant and agreed well with theory. The normal-force-curve slope was practically constant to a Mach number of approximately 1.6 where a rising trend was noted which faired into the theoretical level at a Mach number greater than 2.0.

2. The maximum drag coefficient of the cone model, with reference to the diameter of the base, was approximately 0.60 and of the ogive model, with reference to the diameter of the cylindrical portion, was approximately 2.1.

Langley Research Center,  
National Aeronautics and Space Administration,  
Langley Field, Va., August 24, 1959.

## REFERENCES

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4. Tobak, Murray, and Wehrend, William R.: Stability Derivatives of Cones at Supersonic Speeds. NACA TN 3788, 1956.
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6. Letko, William: Experimental Investigation at a Mach Number of 3.11 of the Lift, Drag, and Pitching-Moment Characteristics of a Number of Blunt Low-Fineness-Ratio Bodies. NASA MEMO 1-18-59L, 1959.
7. Syvertson, Clarence A., and Dennis, David H.: A Second-Order Shock-Expansion Method Applicable to Bodies of Revolution Near Zero Lift. NACA Rep. 1328, 1957. (Supersedes NACA TN 3527.)

TABLE I  
PHYSICAL CONSTANTS FOR MODELS TESTED

Constant	Cone	Ogive
W, lb	83.5	85.0
$I_X$ , slug-ft <sup>2</sup>	.211	.218
$I_Y$ , slug-ft <sup>2</sup>	1.387	1.505
$I_Z$ , slug-ft <sup>2</sup>	1.387	1.505
$x_{cg}/l$	.495	.496
d (ref.), ft	1.167	.667
$l$ , ft	2.458	2.371
S, sq ft	1.070	.348

TABLE II  
VALUES USED TO DETERMINE SLOPE OF NORMAL-FORCE  
COEFFICIENTS AND DYNAMIC STABILITY

Mach number	$\omega_0$	$\lambda_0$	$\Delta\lambda$	$\Delta\omega$	$\frac{I_X \left(1 - \frac{I_X}{4I}\right)}{\left(1 - \frac{I_X}{2I}\right)^2}$	$\frac{dC_m}{dC_N}$ or $\frac{dC_n}{dC_Y}$
Cone						
2.85	72.5	-4.75	0	-4.5	0.171	-0.34
2.47	58.7	-2.89	0	-3.0	.171	-.32
2.06	50.0	-3.98	0	-3.0	.171	-.30
1.03	20.7	-1.57	0	-1.0	.171	-.29
.88	17.0	-1.00	0	-1.0	.171	-.24
.32	4.6	-.34	0	-1.0	.171	-.20
Ogive						
1.86	<sup>a</sup> 27.7	(b)	(b)	-1.0	0.163	-0.25
1.53	18.0	-1.63	0	-1.0	.163	-.20
.81	10.0	-.61	0	-1.5	.163	-.23
.64	6.5	-.36	0	-.7	.163	-.18

<sup>a</sup>Qualitative value.

<sup>b</sup>Reliable value was not obtained.

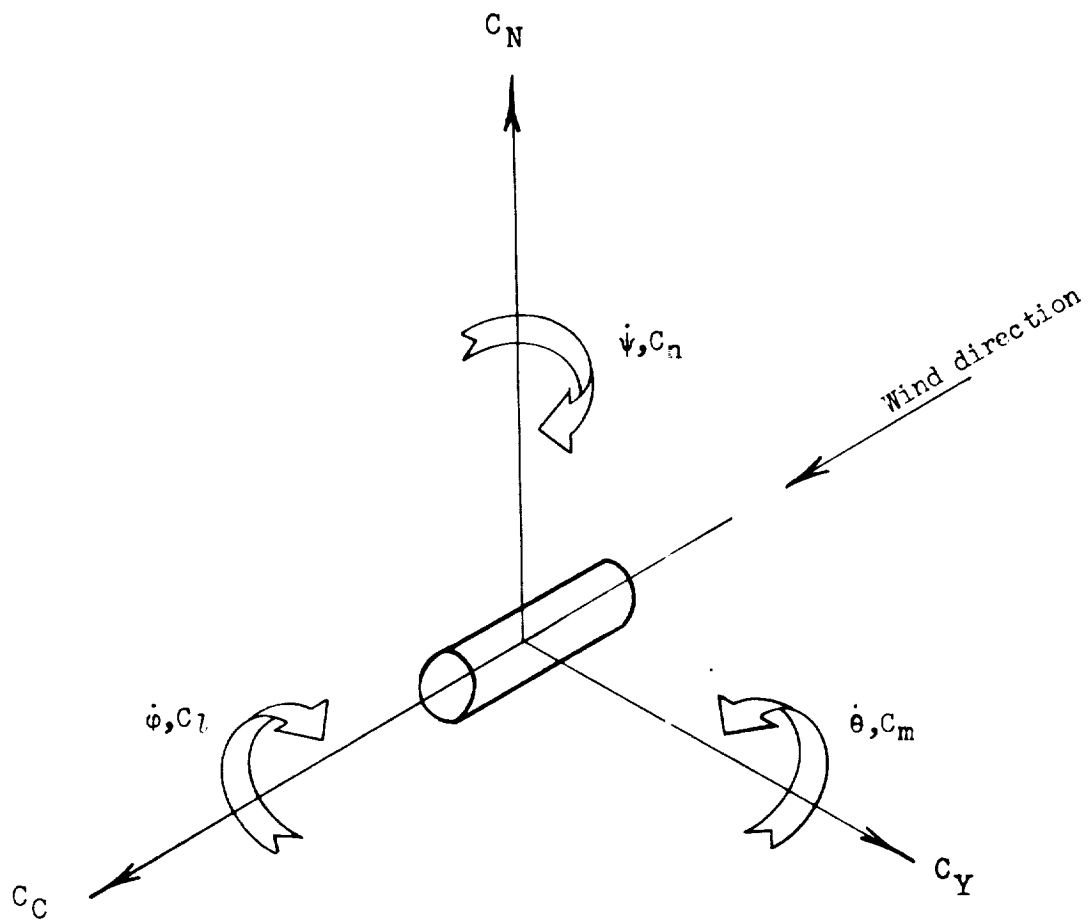
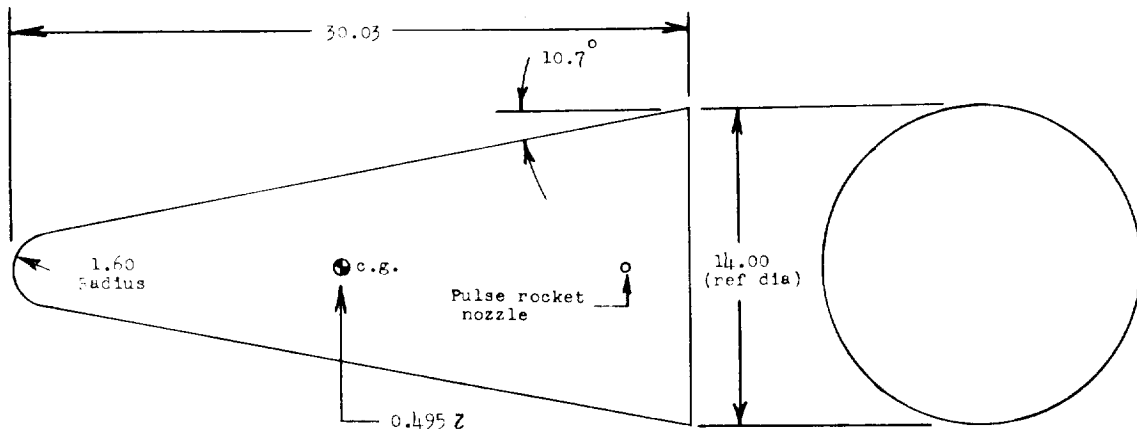
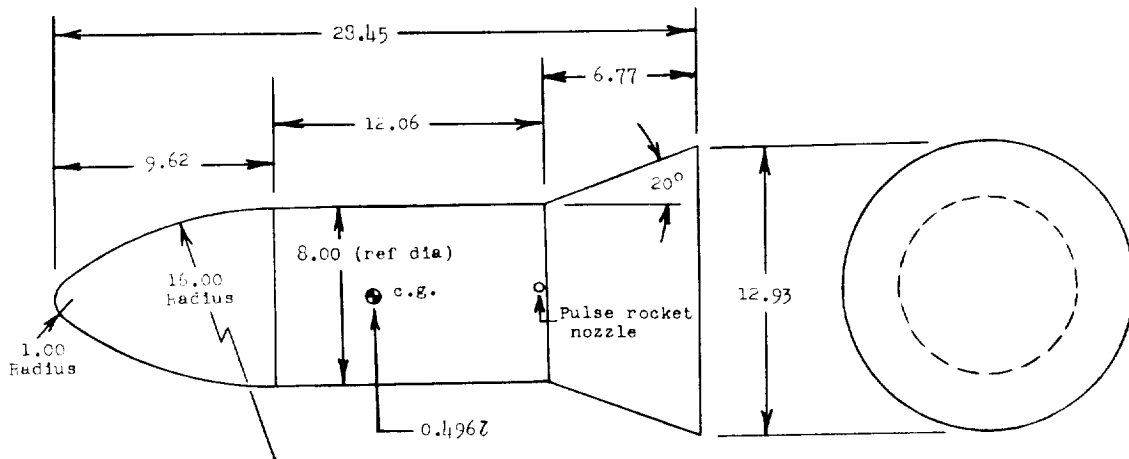


Figure 1.- Axes system with origin at center of gravity. Positive directions of force and moment coefficients and angular velocities are indicated by the arrows.

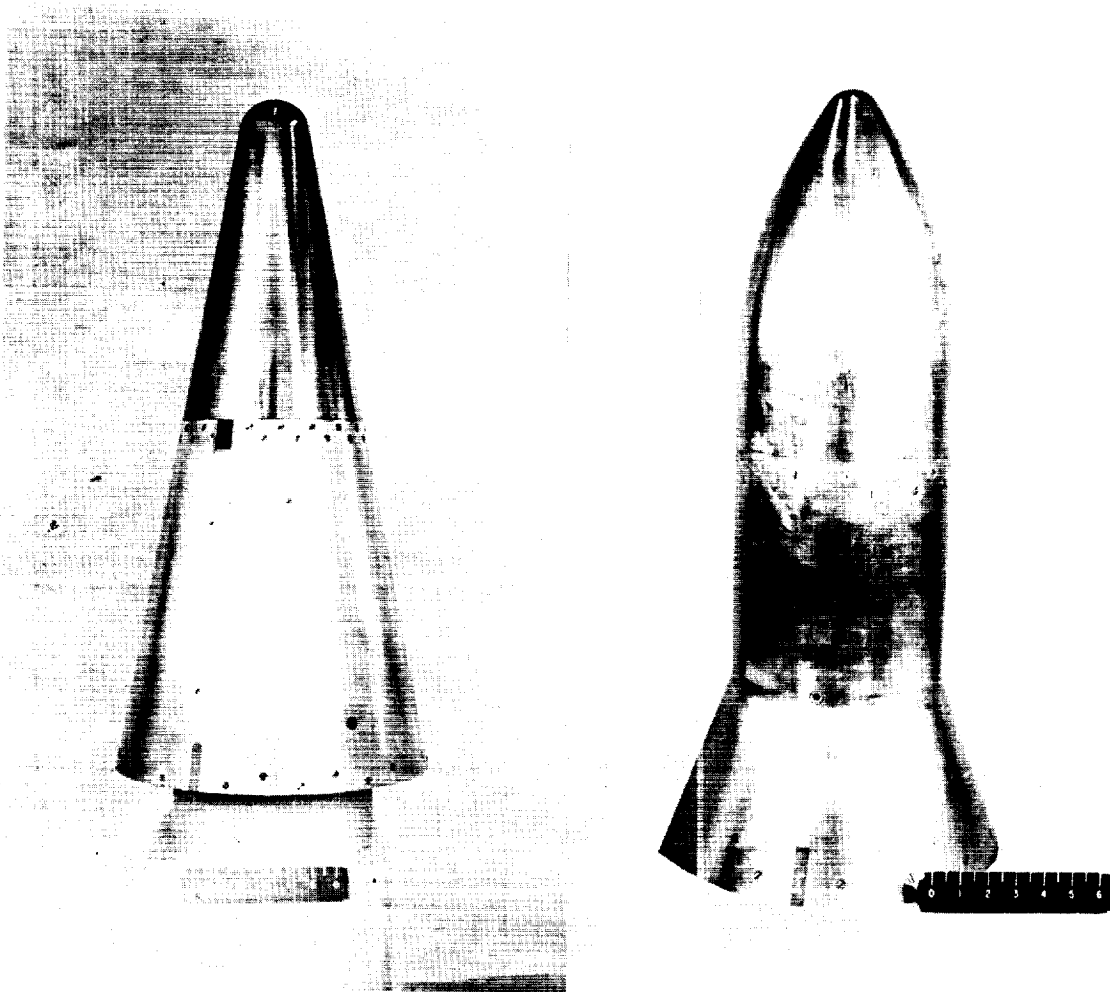


(a) Cone model.



(b) Ogive model.

Figure 2.- Drawings of models tested. All dimensions are in inches.

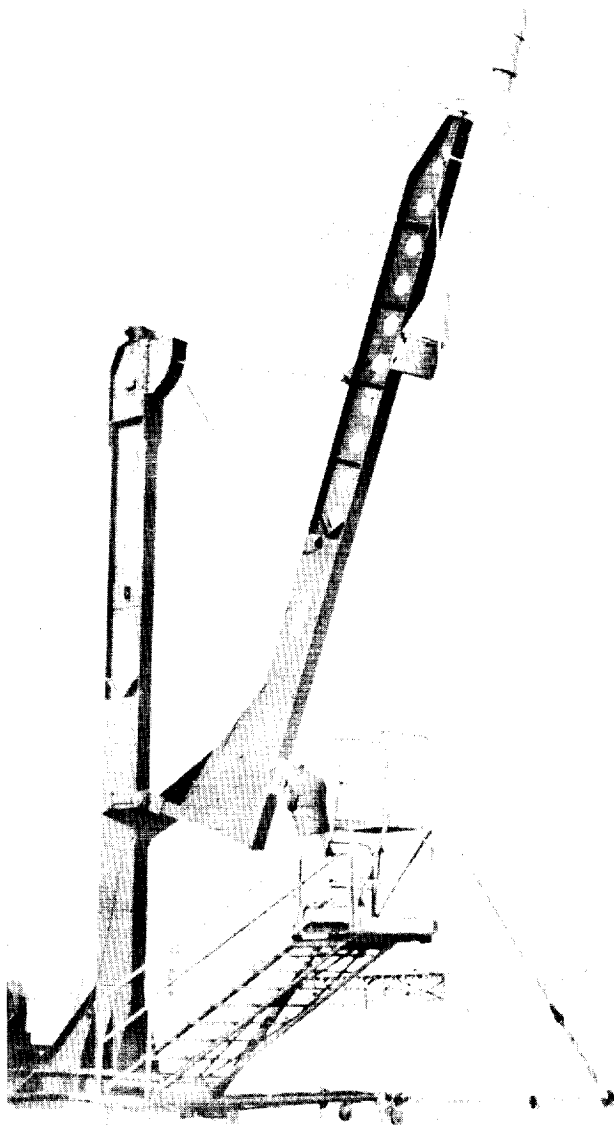


(a) Cone model.

(b) Ogive model.

Figure 3.- Photographs of models tested. L-59-6018





(c) Ogive model on booster in launching position. L-59-714

Figure 3.- Concluded.

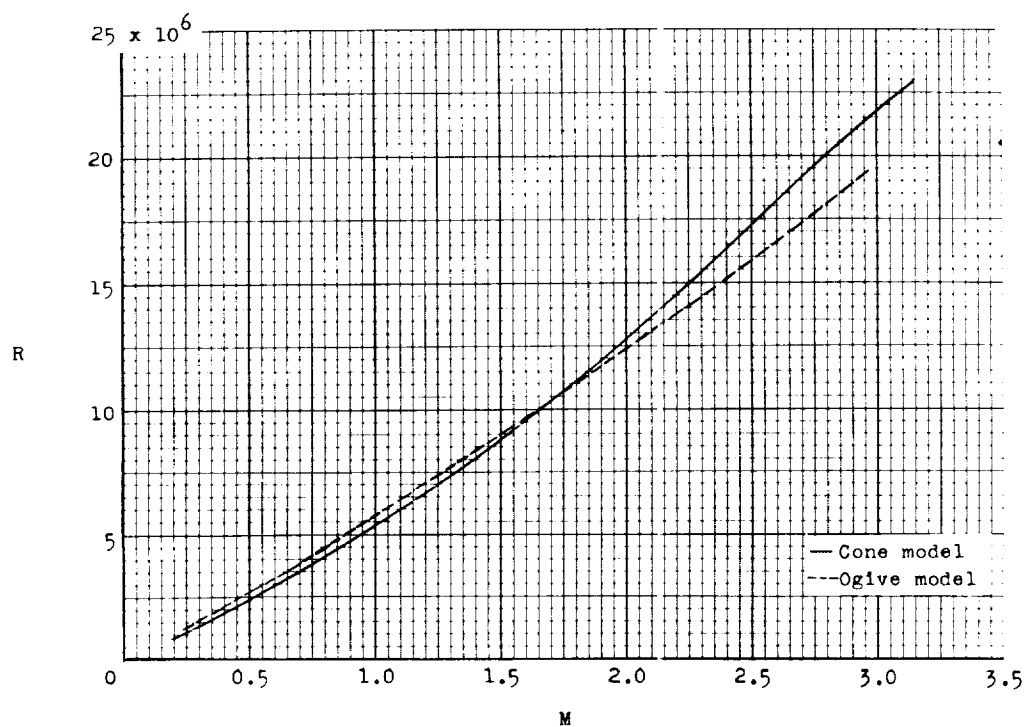


Figure 4.- Test Reynolds number per foot.

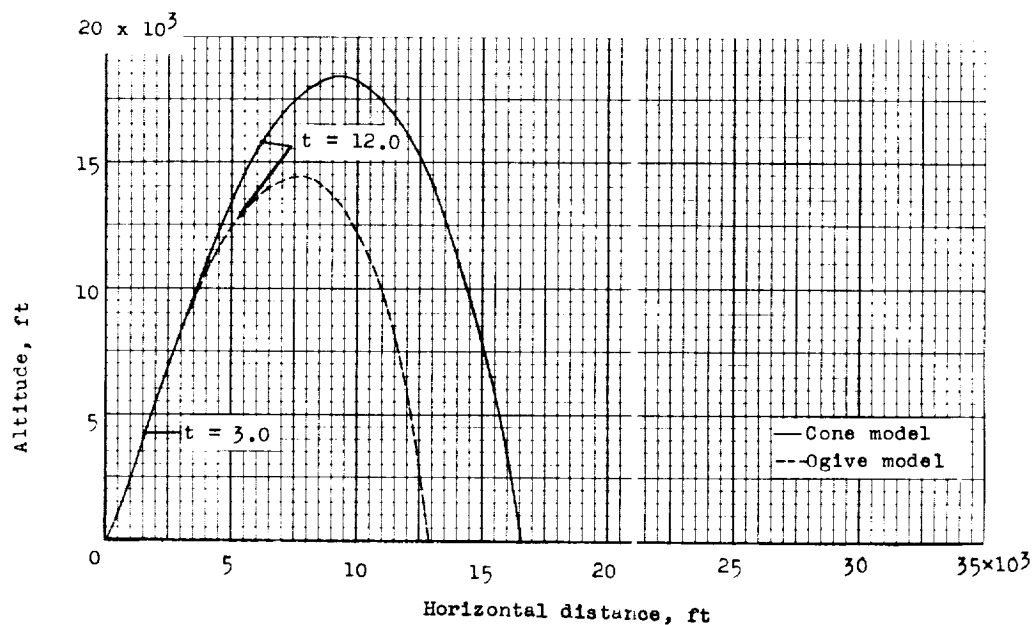


Figure 5.- Flight paths of models tested.

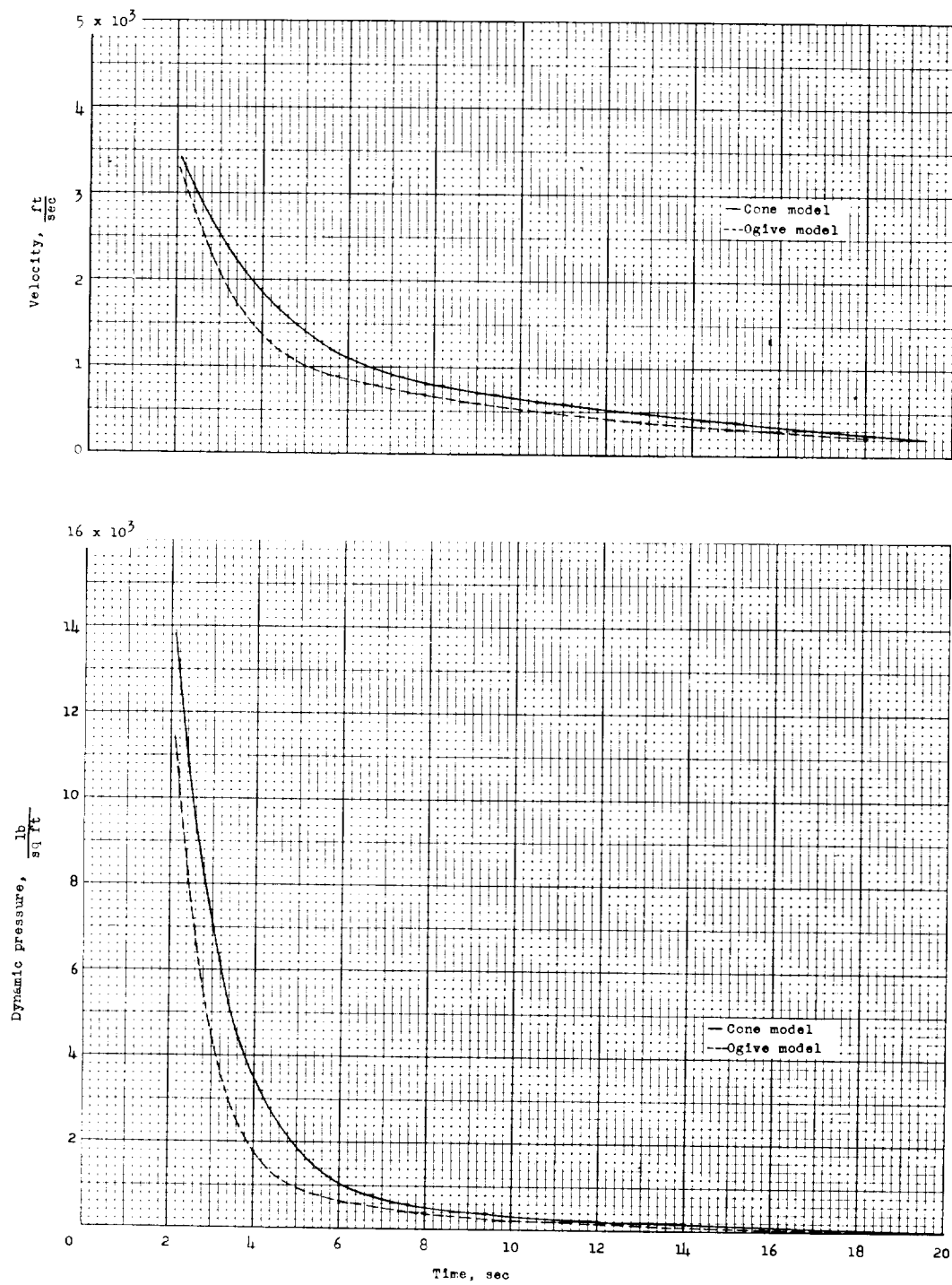


Figure 6.- Velocity and dynamic pressure of models tested.

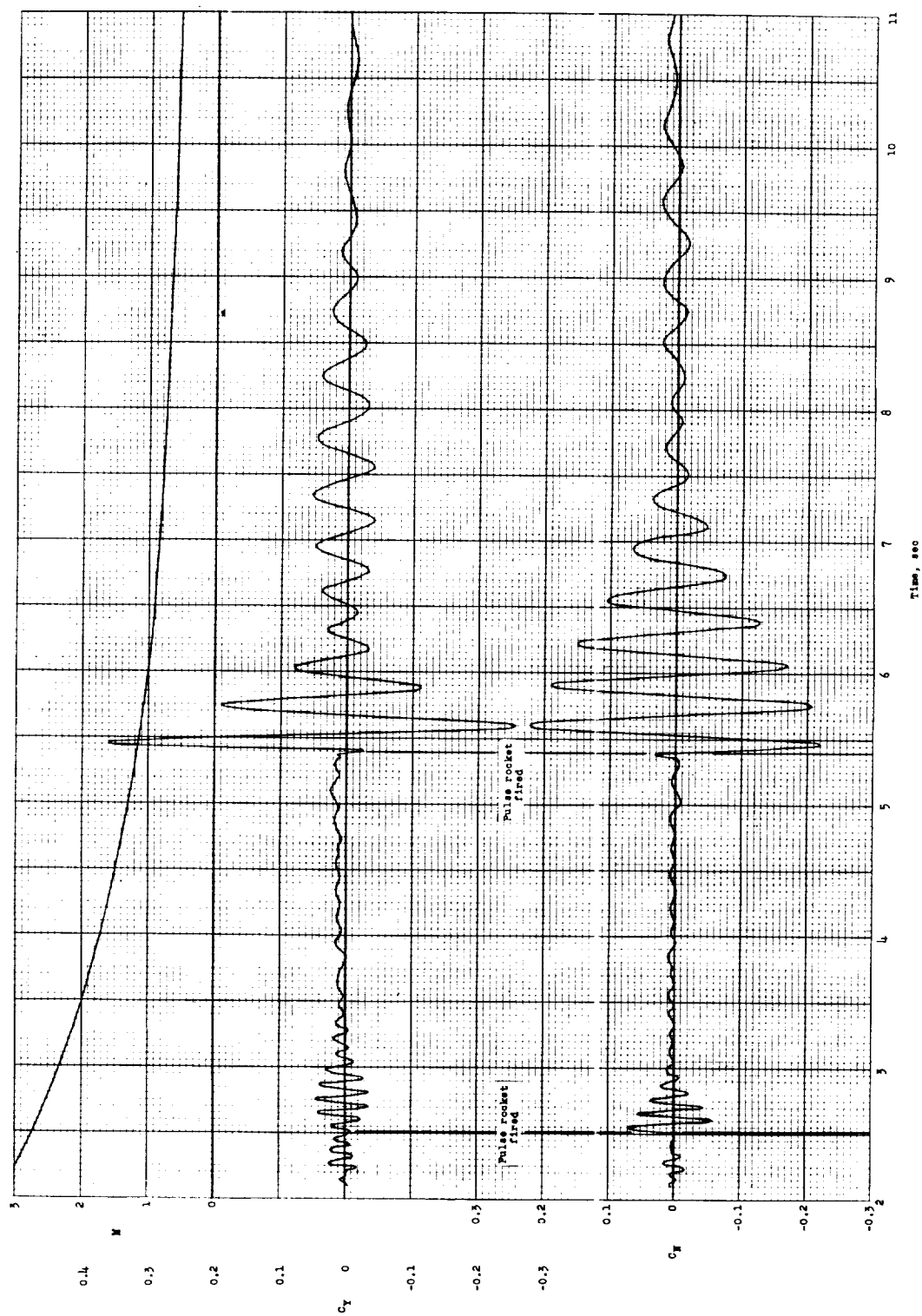


Figure 7.- Time history of cone model.

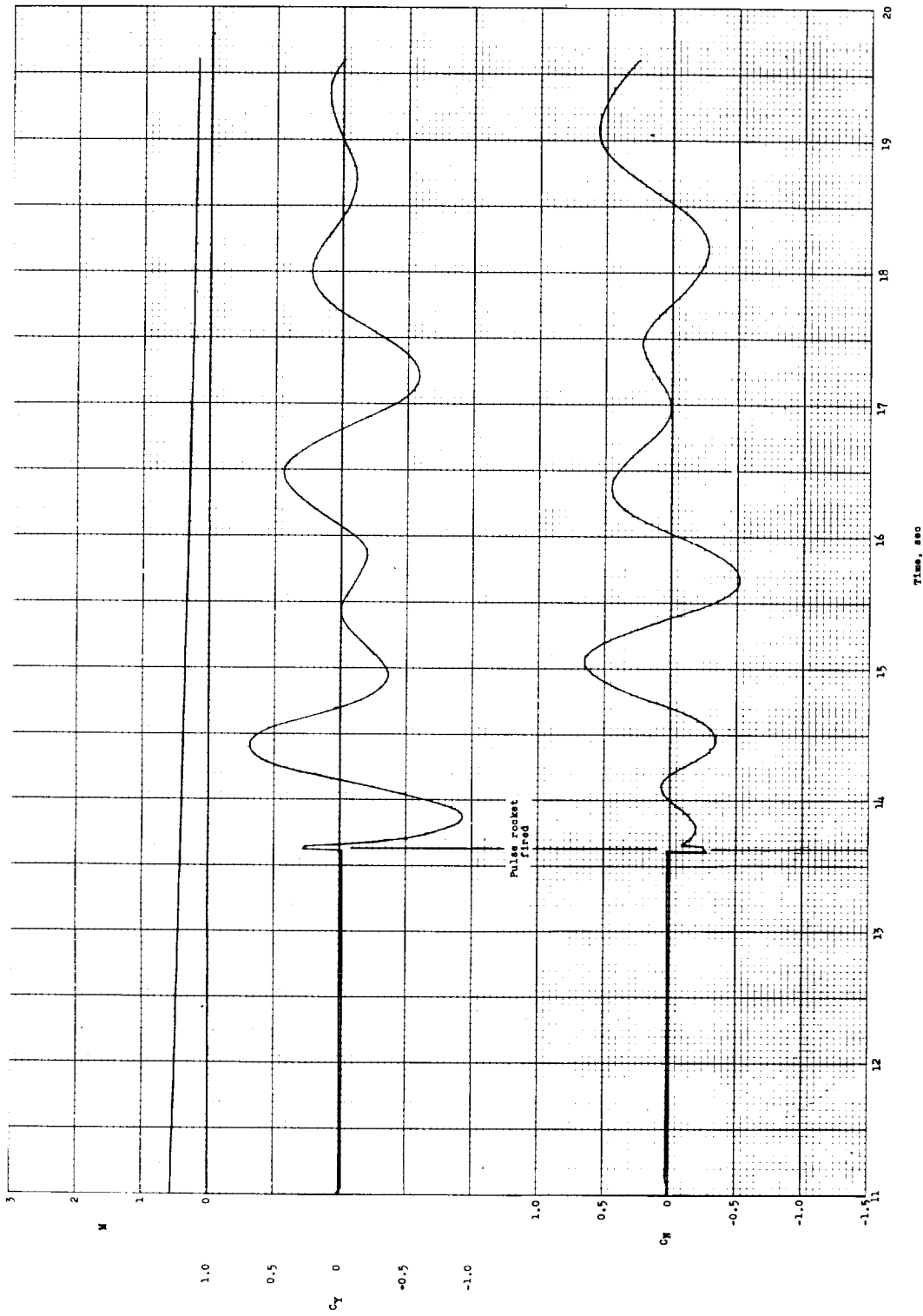


Figure 7.- Concluded.

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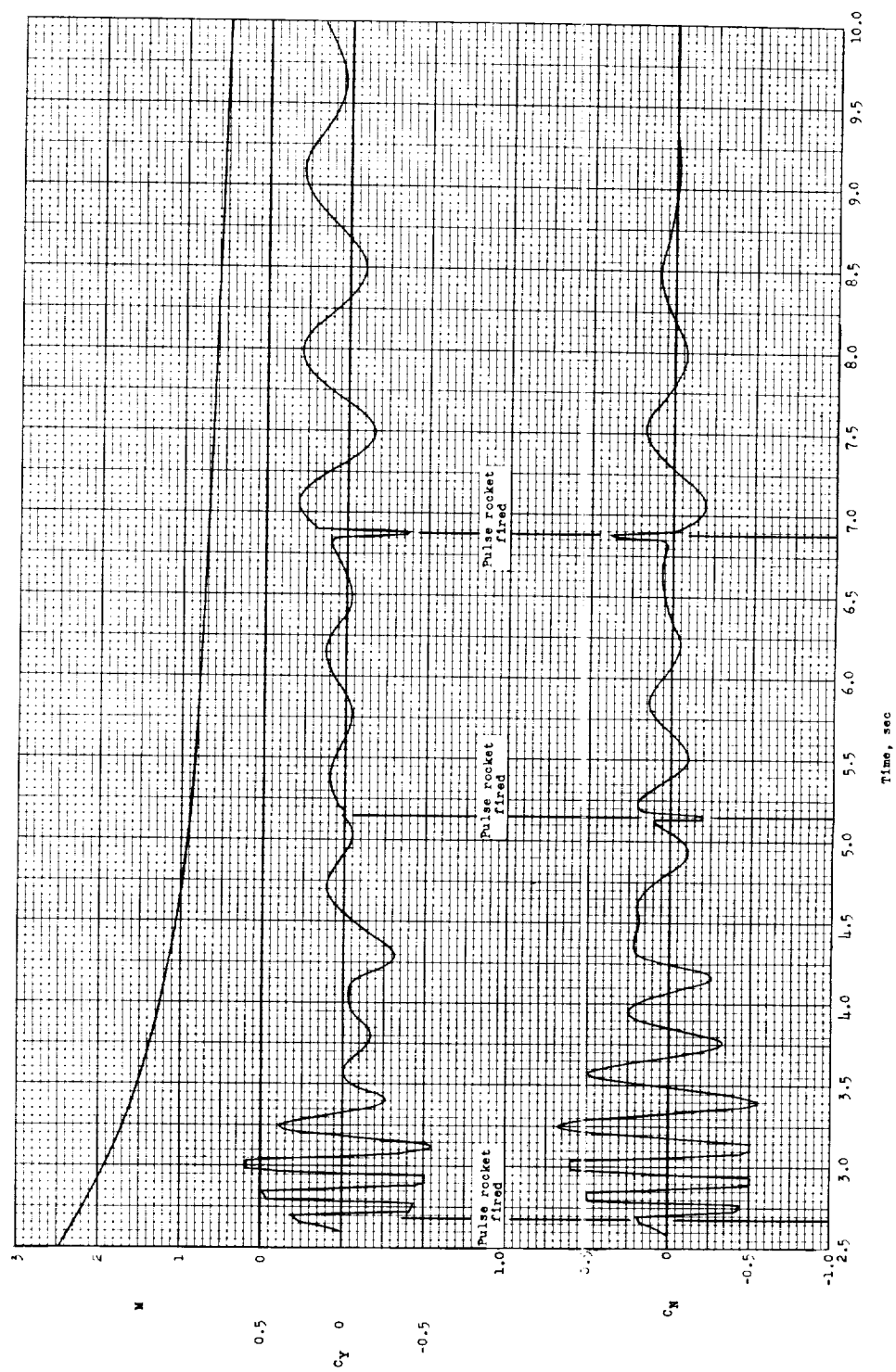
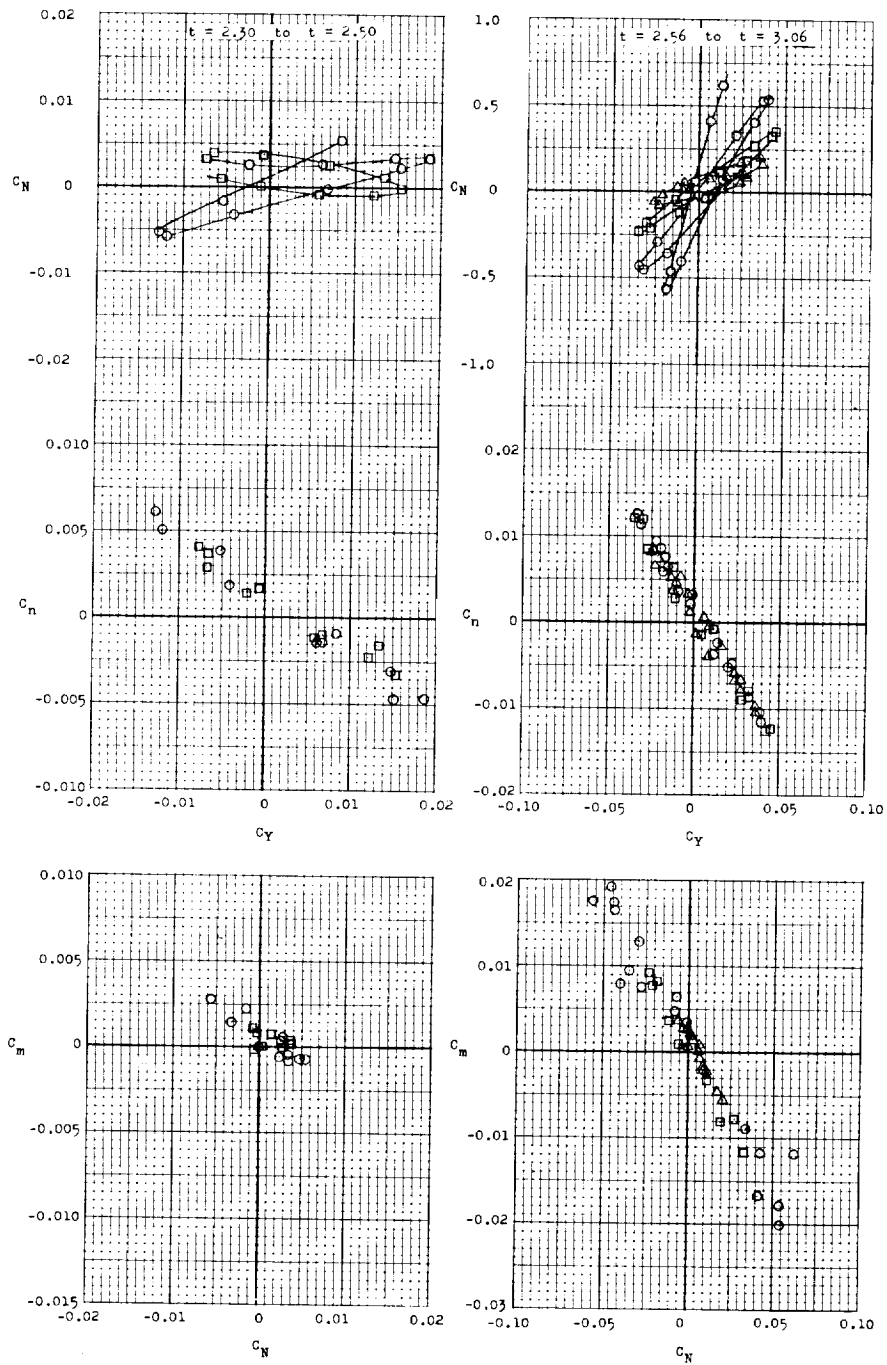


Figure 8.- Time history of ogive model.

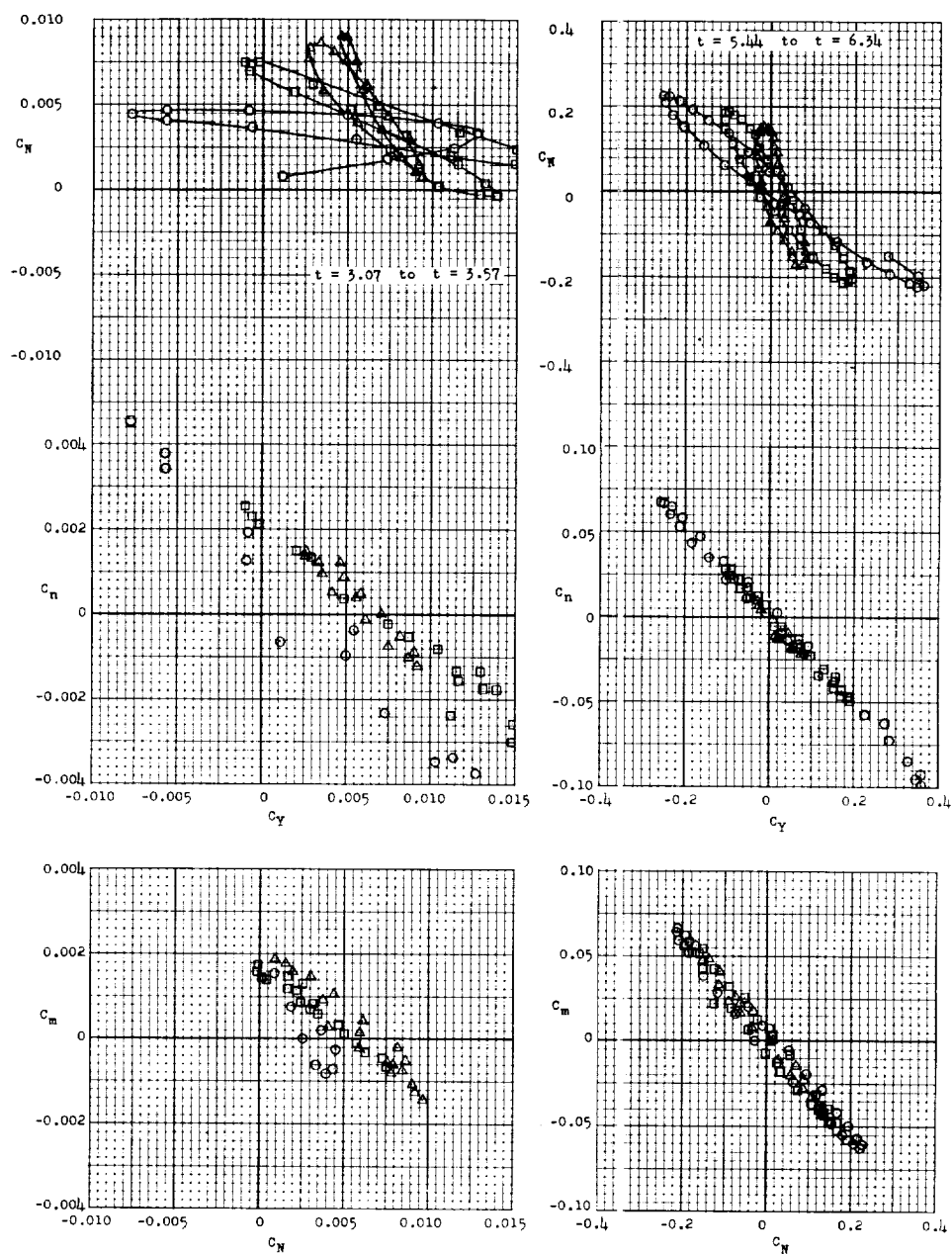
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(a)  $M = 2.95$  to  $M = 2.75$ .

(b)  $M = 2.68$  to  $M = 2.26$ .

Figure 9.- Basic-data cross plots of force and moment coefficients. Cone model. The time sequence is indicated by the symbols  $\odot$ ,  $\square$ ,  $\triangle$ .

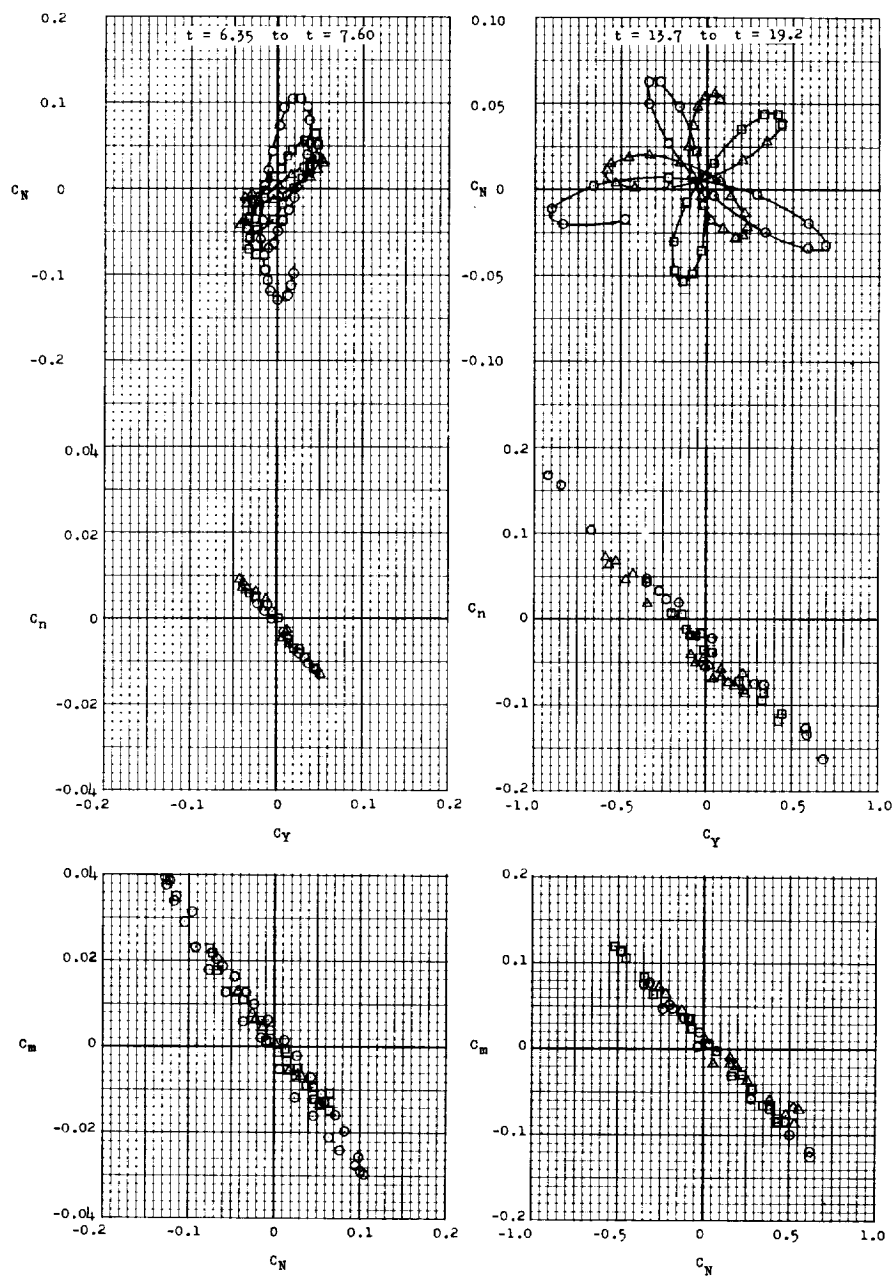


(c)  $M = 2.27$  to  $M = 1.95$ .

(d)  $M = 1.17$  to  $M = 0.93$ .

Figure 9.- Continued.





(e)  $M = 0.93$  to  $M = 0.78$ .

(f)  $M = 0.42$  to  $M = 0.21$ .

Figure 9.- Concluded.

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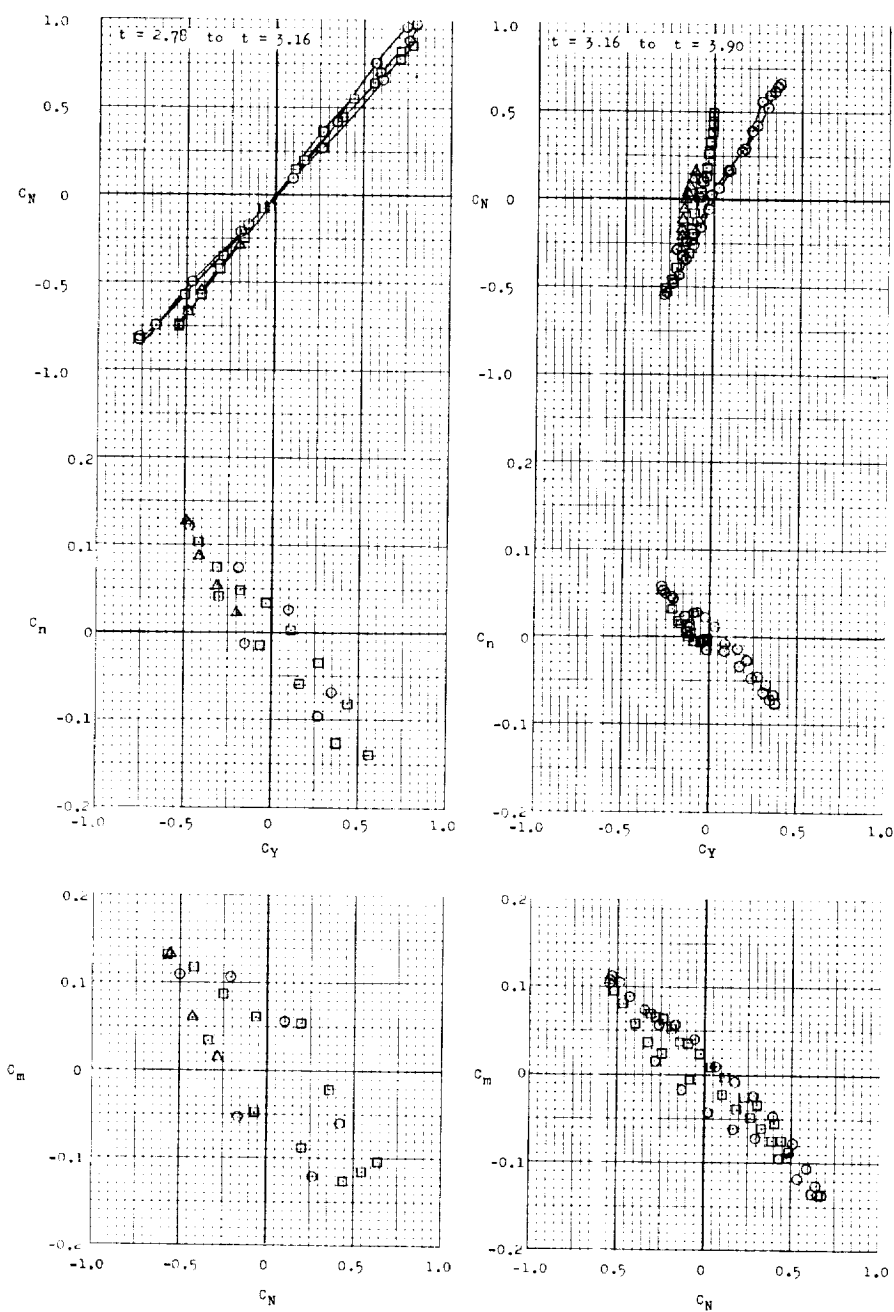
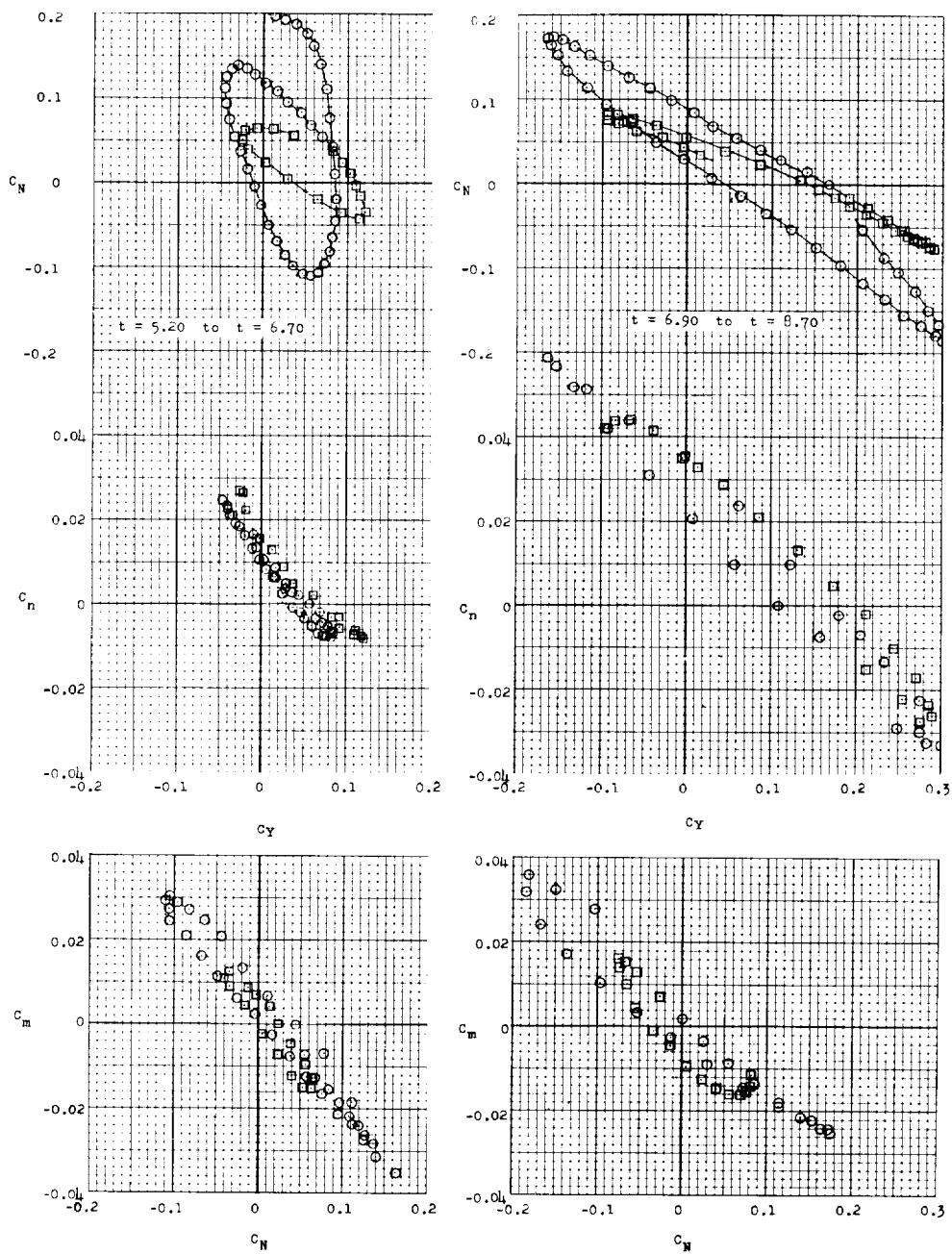
(a)  $M = 2.14$  to  $M = 1.77$ .(b)  $M = 1.77$  to  $M = 1.30$ .

Figure 10.- Basic-data cross plots of force and moment coefficients. Ogive model. The time sequence is indicated by the symbols,  $\odot$ ,  $\square$ , and  $\triangle$ .

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(c)  $M = 0.90$  to  $M = 0.72$ .

(d)  $M = 0.70$  to  $M = 0.56$ .

Figure 10.- Concluded.

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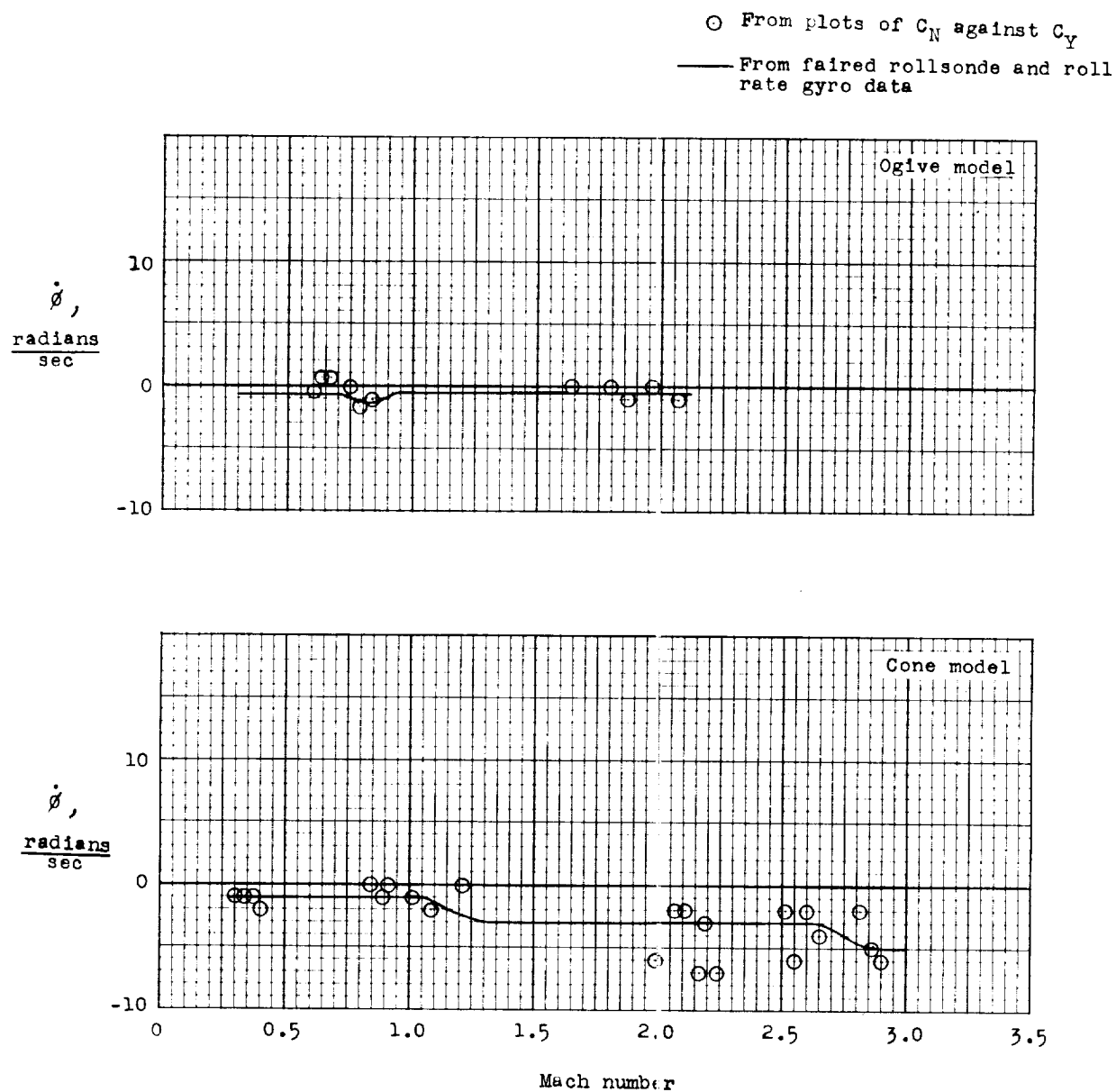


Figure 11.- Variation of rolling velocity with Mach number.

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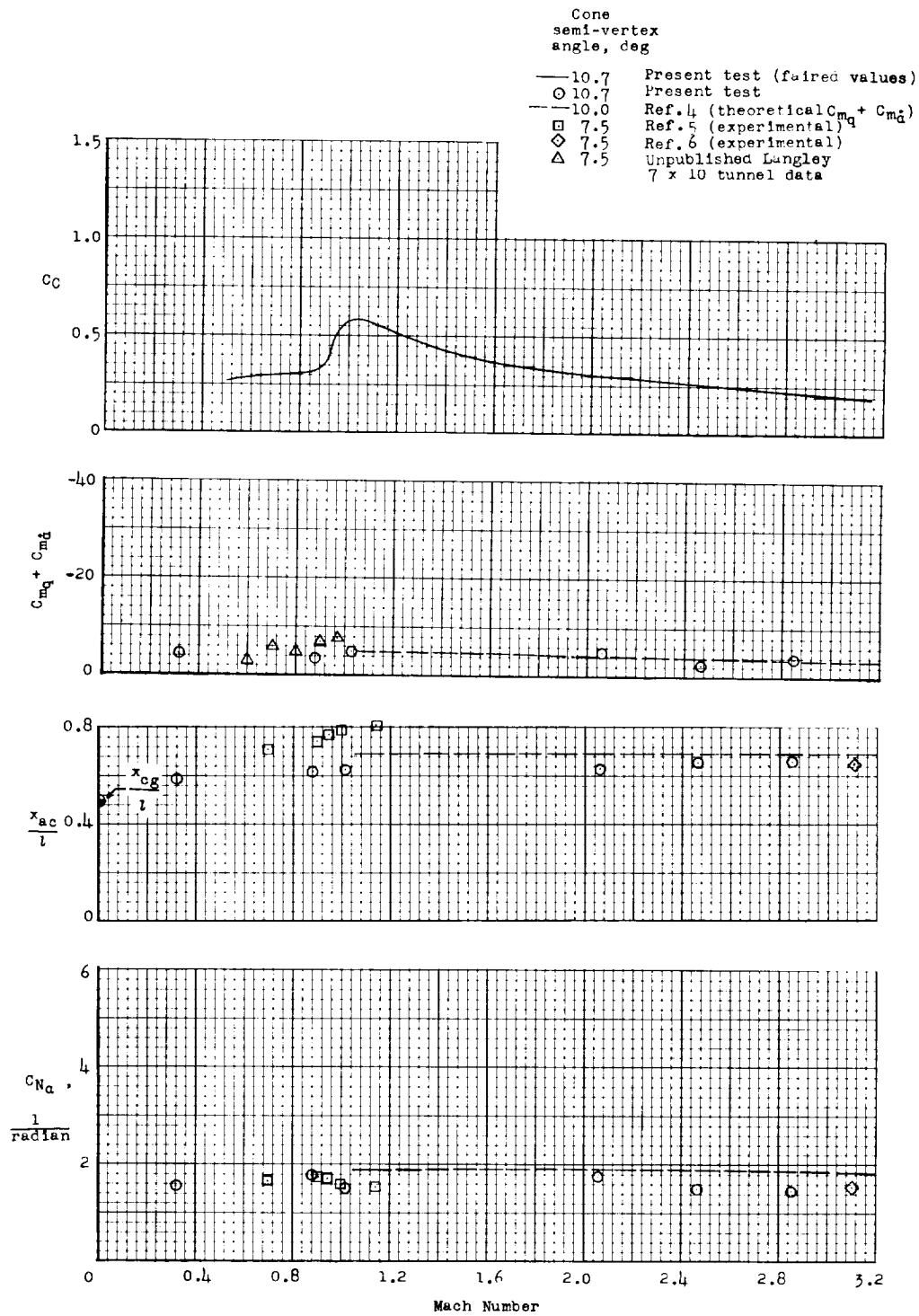


Figure 12.- Aerodynamic characteristics of the cone model.

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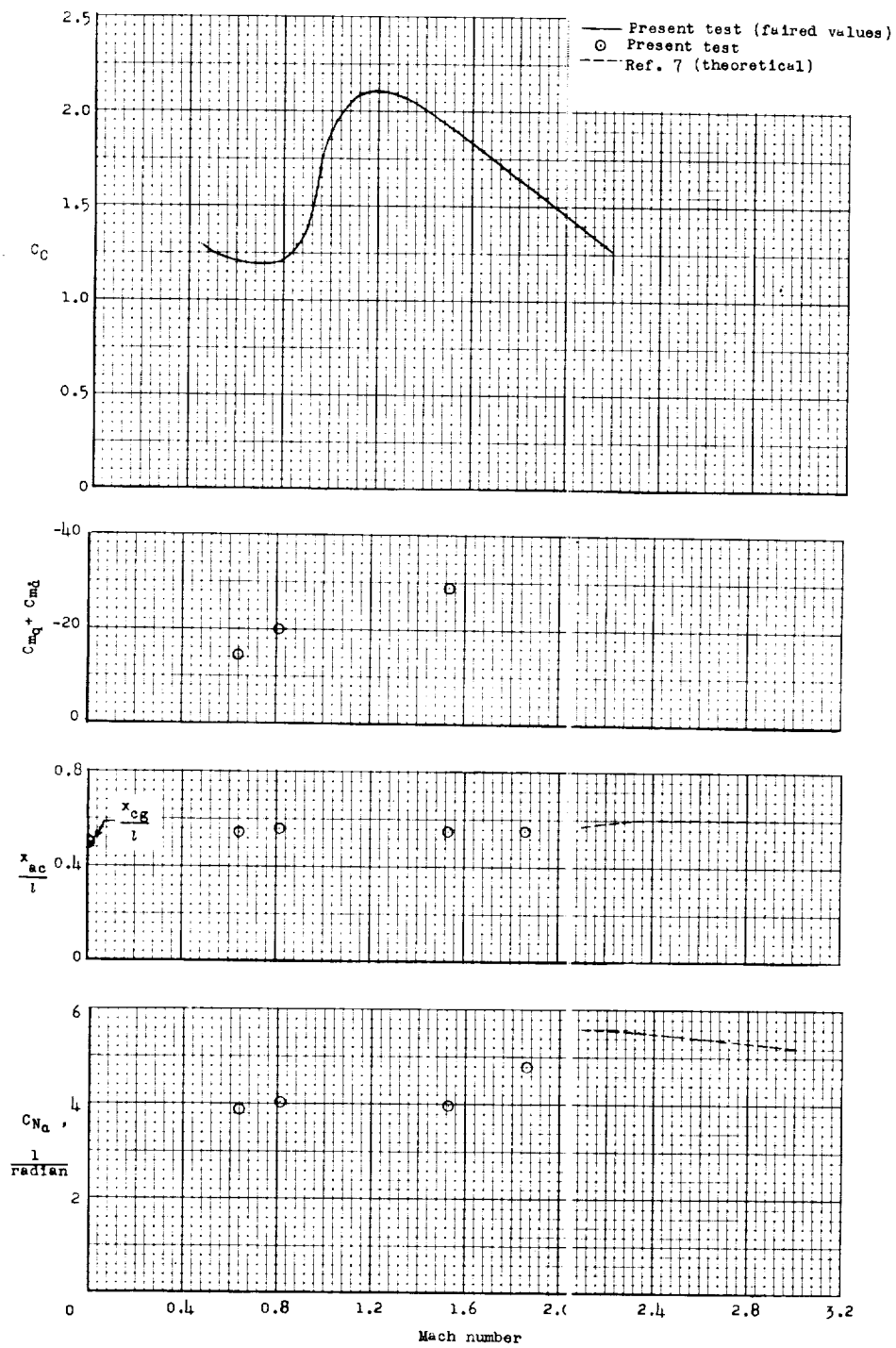


Figure 13.- Aerodynamic characteristics of the ogive model.

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